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Observations of Fine Structure in HF Radio Signals Propagated Around the World

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December 1970

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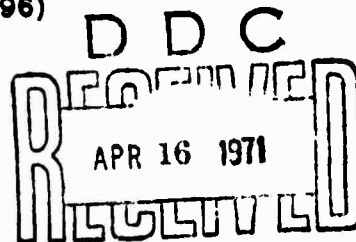
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RadioScience Laboratory
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ABSTRACT

A fine structure has been observed in oblique ionograms taken over round-the-world paths. This structure appears as roughly horizontal striations on the time-delay vs frequency plots of the received signals, and several examples of these ionograms, taken during the course of a year, are shown.

The form of the structure varies with the time of day; however, a degree of overall constancy can be found in records taken six months apart. It is thought that the fine structure represents a resolution of the paths taken by the RTW signal.

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Numerous studies of round-the-world (RTW) propagation of high-frequency radio signals (3 to 30 MHz) have been made since the first report of the phenomenon in 1927 [1, 2]. For the most part, these investigations have concentrated on such properties as propagation time, attenuation, and the effects of azimuth, time of day, and geomagnetic activity [3, 4, 5, 6, 7, 8, 9]. Limitations of equipment and technique prevented a detailed study of the morphology of the RTW signals with respect to radio frequency and propagation time.

Recently, however, these limitations have been reduced significantly by the development of the sweep frequency continuous wave (SFCW) sounding technique which makes possible a greatly improved resolution of frequency and time as compared to earlier sounding methods [10, 11]. This report covers an application of the SFCW sounding technique to the study of RTW propagation and describes the resulting observations of a fine structure in single-orbit RTW ionogram.

Figure 1 is an RTW ionogram in which this structure is particularly well defined. Note the striated appearance of the signal at frequencies above 22 MHz. The record was taken over the long path from a transmitter

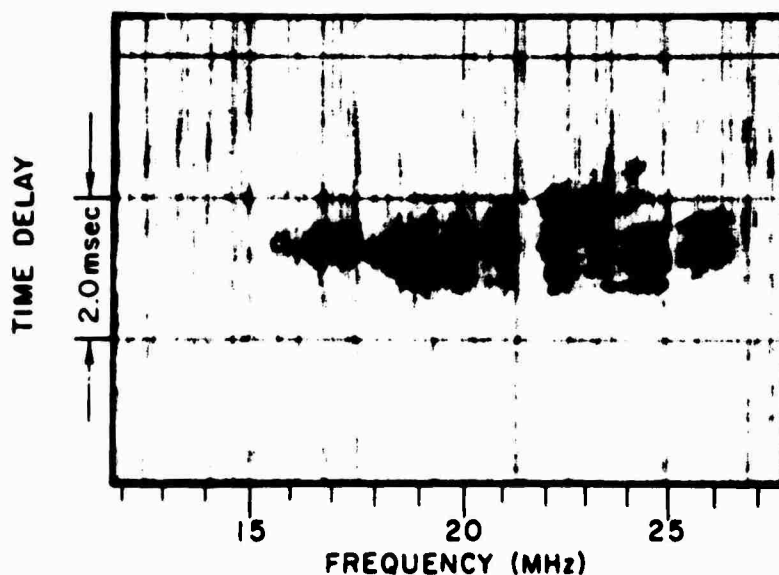


Fig. 1. AN RTW IONOGRAM TAKEN AT 1855 UT, 20 OCTOBER 1969, FROM TRANSMITTER NEAR BEARDEN, ARKANSAS, TO RECEIVER NEAR LOS BANOS, CALIFORNIA. Instantaneous signal amplitude is represented by the darkening of the recording paper.

located near Bearden, Arkansas (33.7° N, 92.6° W) to a receiver near Los Banos, California (37.2° N, 120.9° W). This path covers approximately 93 percent of the complete great circle passing through the two sites; its orientation with respect to the United States and the positions of the sites are shown in Fig. 2.

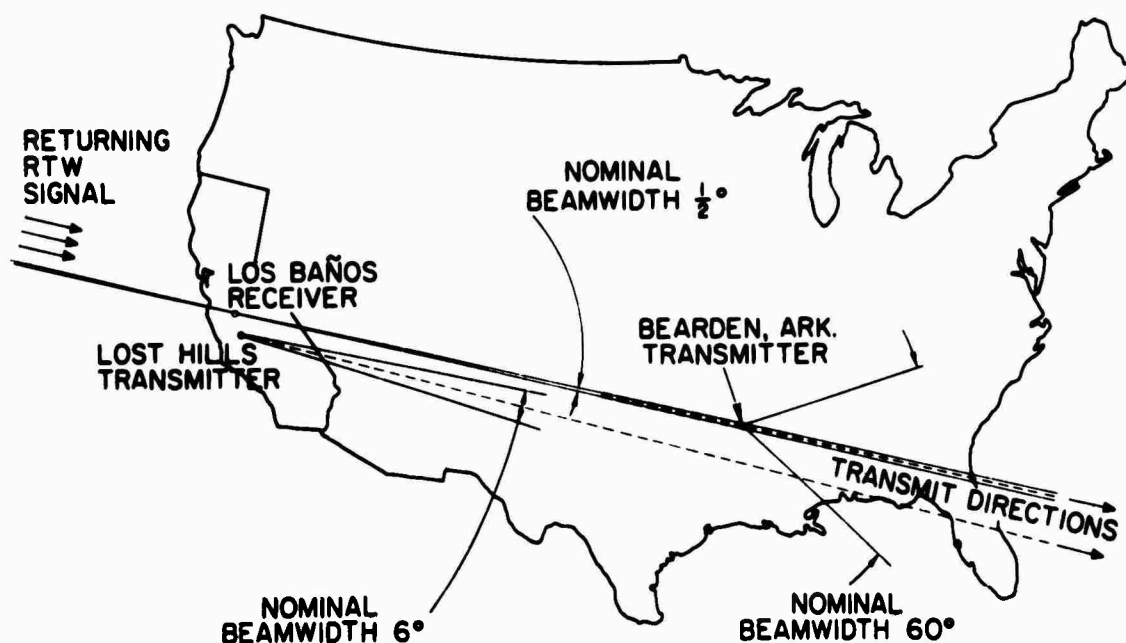


Fig. 2. LOCATIONS OF FIELD SITES. Dashed lines indicate portions of the great-circle signal paths.

The transmitted signal was a 100-W SFCW signal whose frequency was swept linearly from 12 to 27 MHz at a rate of 250 kHz/sec. It was radiated eastward along the Bearden-Los Banos great circle, using a log-periodic antenna with a 60° beamwidth. The returning RTW signal was received from the west along the same great circle, using a 2.55 km linear HF receiving array with a steerable $1/2^{\circ}$ beam. (Reference 12 contains a detailed description of this array.) The signal was recorded in real time in the standard ionogram format of time delay vs frequency. Because the transmitter and receiver were separated geographically, a close synchronization of the clocks controlling the two systems was necessary to measure precisely the absolute time of propagation; this

was not done when the record of Fig. 1 was taken and, consequently, only the relative time delay is shown.

Figure 3 presents six additional examples of fine structure in RTW ionograms. These records were selected from a series of RTW ionograms collected during the year following the initial October 1969 observations, and they reveal several variations of the observed patterns. The first four records were obtained by using a transmitter of higher power (30 kW) located near Lost Hills, California (35.7° N, 119.5° W). These SFCW transmissions covered the frequency range of 9 to 27 MHz at the rate of 250 kHz/sec and were directed eastward, using a linear antenna array with a midband beamwidth of 6° . Although the relative locations of the two sites are such that the RTW signals from Lost Hills received at Los Banos could not follow a great circle (Fig. 2), the signals do make essentially a full RTW circulation. The cesium clocks controlling both sites were synchronized when the ionograms of Fig. 3c,d were taken so that the absolute propagation time was recorded for these signals. The propagation time was also recorded for the Bearden signals (Fig. 3e,f) but to a lesser accuracy.

For some time, it has been recognized that the duration of a received RTW pulse is greater than the duration of the transmitted pulse and that the magnitude of this pulse widening varies inversely with the frequency. The generally accepted explanation for this phenomenon is that the RTW signal arrives at the receiver after traveling a number of paths of different lengths and, as a result, the same transmitted pulse is received at several closely spaced intervals of time. The number of these propagation paths is thought to decrease with increasing frequency, which accounts for the lessened pulse widening at higher frequencies and is in accord with observations of ionospherically propagated signals over shorter ranges. In this light, it is interesting to note that the inverse-frequency pulse spreading exhibited by the last five records in Fig. 3 apparently is caused by a drop in the number of striations as the frequency increases. This observation is true for most of the RTW ionograms taken to date. In addition, there is a strong likeness between the "hooks" that terminate striations in Fig. 3c,d,e and the MUF nose feature that often is found in oblique ionograms taken over shorter

paths (Fig. 4). We believe that the fine structure reported here is a resolution of the propagation paths (or modes) of the RTW signal and that each striation represents one or more modes.

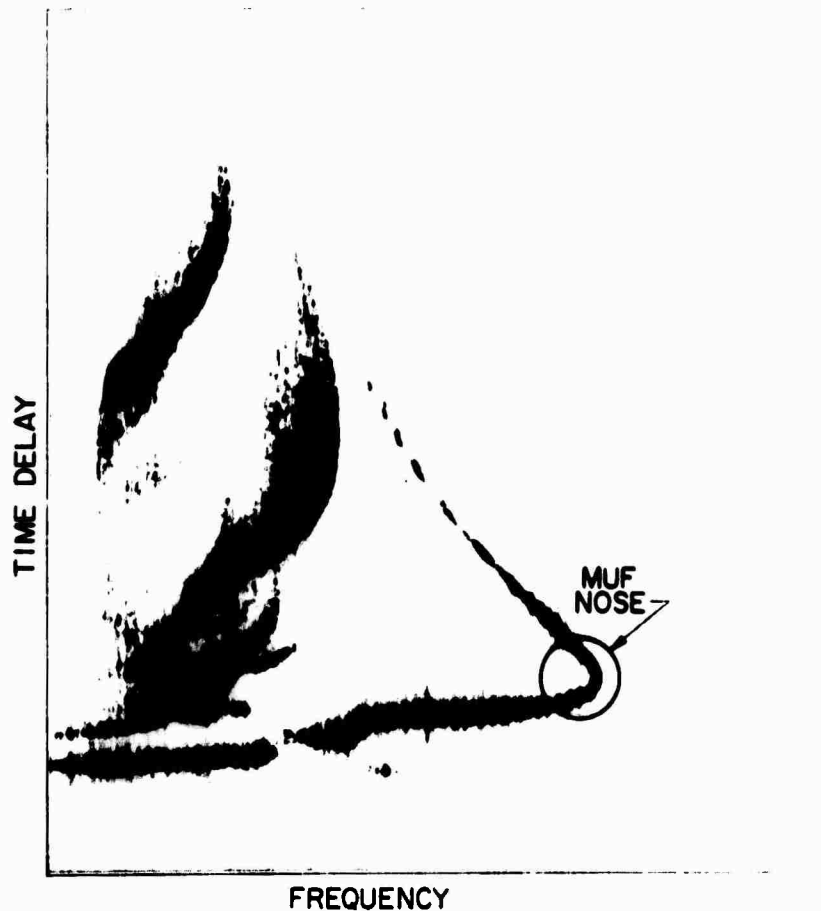


Fig. 4. SHORT-PATH OBLIQUE IONOGRAM ILLUSTRATING THE MUF NOSE FEATURE. This record was taken between Bearden and Los Banos at 2018 UT, 24 September 1970.

Recognizable similarities can be seen between the Lost Hills ionograms of Fig. 3a,b and between the Bearden records of Figs. 1 and 3e. These records were taken at widely separated times, indicating that there is a degree of overall constancy in the RTW mode structure. Variations over a time scale of a few minutes are illustrated by the records in Fig. 3c,d.

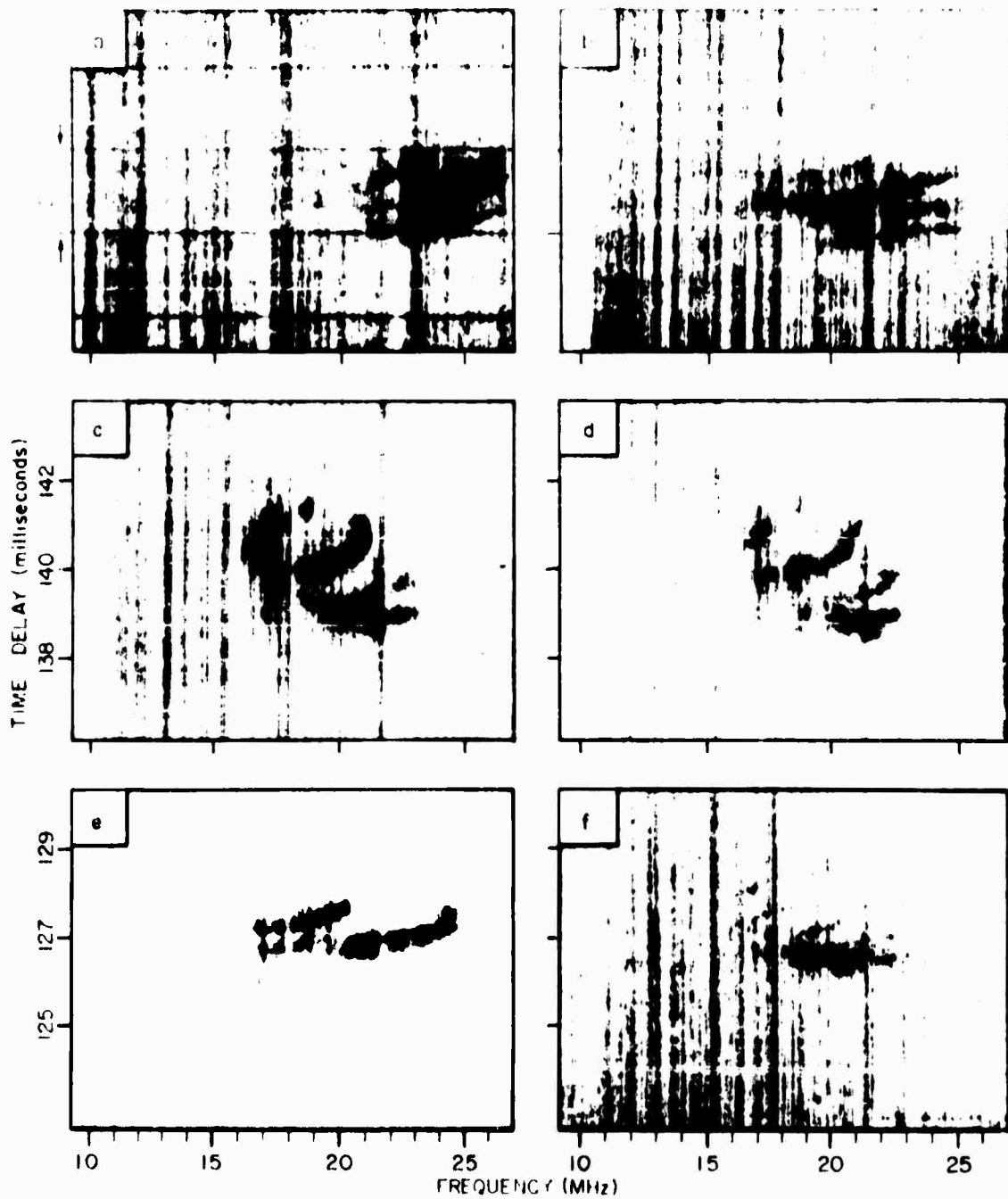


Fig. 3. ADDITIONAL EXAMPLES OF RTW IONOGRAMS. Ionograms a,b,c, and d were transmitted from Lost Hills; e and f were transmitted from Bearden. All were received at Los Angeles, California. Times and dates are (a) 2216 UT, 20 October 1969, (b) 2012 UT, 16 March 1970, (c) 2056 UT, 1 September 1970, (d) 2100 UT, 1 September 1970, (e) 1822 UT, 29 September 1970, (f) 2121 UT, 23 September 1970.

Intuitively, one would expect to find a great multiplicity of possible ionospheric modes of propagation for HF signals over an RTW path; however, the results presented here imply that only a small number of modes may be effective at any one time. Further recordings of RTW signals are in progress to determine the dependence of the mode structure on time of day, season, and condition of the ionosphere and to measure more accurately the arrival times and azimuths of the signals. These data should help to establish the mechanism responsible for the observed mode structure.

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